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RESEARCH ARTICLE

On regular frames near rotating black holes

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Abstract
We consider the metric of a generic axially symmetric rotating stationary black hole. The general approach is developed that enables us to construct coordinate frame regular near the horizon. As explicit examples, the Kerr and Kerr–Newmann-(anti-)de Sitter metrics are considered. It is shown how the rotational versions of the Painlevé–Gullstrand and Doran coordinates appear in this scheme as particular cases. For the $2+1$ version of the metric the direct generalization of the Lemaître coordinate system is obtained. It is shown that the possibility of introducing a regular frame is indirectly related to the constancy of a black hole angular velocity and the rate with which the metric coefficient responsible for the rotation of spacetime tends to it.

Keywords Horizon · Rotating black hole · Dirty black holes

1 Introduction

The metric of the Kerr black hole is well known [1]. Nonetheless, its description continues to attract attention since different coordinate frames are relevant in different physical contexts. First of all, it is necessary to have well-defined coordinates near the horizon where the standard Boyer–Lindquist ones [2] fail. To this end, new coordinate systems were suggested that can be considered as generalization of the Painlevé–Gullstrand coordinates [3,4] from the Schwarzschild case or their modification [5,6]. Meanwhile, in real astrophysical circumstances black holes are surrounded by matter, so their metric may differ from the pure Kerr solutions thus representing so-called "dirty" black holes. This leads to the question of finding regular frames near quite generic rotating black holes. Also, this problem is of obvious general interest on its own right. In doing so, we face with two different but tightly related problems: (i)

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